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RESEARCH DEPARTMENT

REPORT

Television reception over sea paths: the effect of the tide

No. 1970/22

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

TELEVISION RECEPTION OVER SEA PATHS: THE EFFECT OF THE TIDE

Research Department Report No. **1970/22**
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TELEVISION RECEPTION OVER SEA PATHS: THE EFFECT OF THE TIDE

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TELEVISION RECEPTION OVER SEA PATHS: THE EFFECT OF THE TIDE

SUMMARY

On oversea paths within the horizon, the received field strength is the vector sum of a direct component and a component reflected from the surface of the sea. If the level of the sea varies, the relative phase of the reflected component alters and causes field strength variations. To determine the effect of these variations on u.h.f. television reception, a series of measurements and subjective assessments have been made in various areas of the United Kingdom.

It is concluded that, for horizontally polarised signals, field strength changes of more than 40 dB can occur at unobstructed locations. The range of fading is reduced in built-up and diffracted-field areas. It is also reduced by using vertical polarisation. The variation of signal level is generally accompanied by multipath propagation and frequency-selective effects, which cause severe degradation of the television service in certain coastal areas. Areas likely to suffer such degradation are detailed.

1. INTRODUCTION

It is well known that the ground-reflected component of a transmitted signal can combine with the directly-received component in such a manner as to cause cancellation.

Although it had been realised that this characteristic of propagation might cause difficulties in u.h.f. reception, this effect is generally unimportant over land paths because of terrain roughness. The receiving aerial height can also generally be adjusted to avoid such field strength minima. However, where the reflection point is the surface of the sea, path geometry varies with the tide, and it may not be possible to obtain a satisfactory position for the receiving aerial.

The report summarises the results of an investigation of these field-strength variations, and their effects on u.h.f. television services.

The measurements are divided into three sections:

(a) Prolonged field-strength recordings of a u.h.f. television transmission (Llanddona) at a BBC link site (Great Ormes Head)

(b) Field-strength measurements of u.h.f. c.w. transmissions in West Cornwall where the variations were first observed

(c) Field-strength measurements and picture quality assessments in a u.h.f. television service area (Wenvoe).

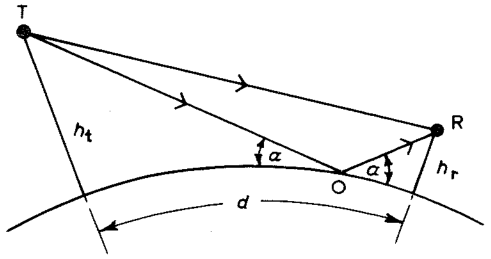

Fig. 1 - Path geometry for two ray propagation over a smooth earth

2. THEORETICAL CONSIDERATIONS

2.1. Conditions for Field Minima

At both v.h.f. and u.h.f. the field received over transmission paths within the horizon comprises the vector sum of the direct signal and that reflected specularly from the surface of the earth. Fig. 1 shows the idealised geometry. For a reflection coefficient of unity this resultant field will be zero* when the two components are in antiphase. This condition occurs when, for wavelength λ

$$\theta + \phi = n + \tfrac{1}{2} \quad (n \text{ being an integer}) \qquad (1)$$

θ is the path difference (in wavelengths) between direct and reflected components

θ equals $2h_t h_r/\lambda d \times \eta$, where

h_t and h_r are the heights of the terminals
d is the path length
η is a modifying factor to take account of earth curvature

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* Neglecting contributions due to any additional reflected components and the effect of divergence due to the earth's curvature.

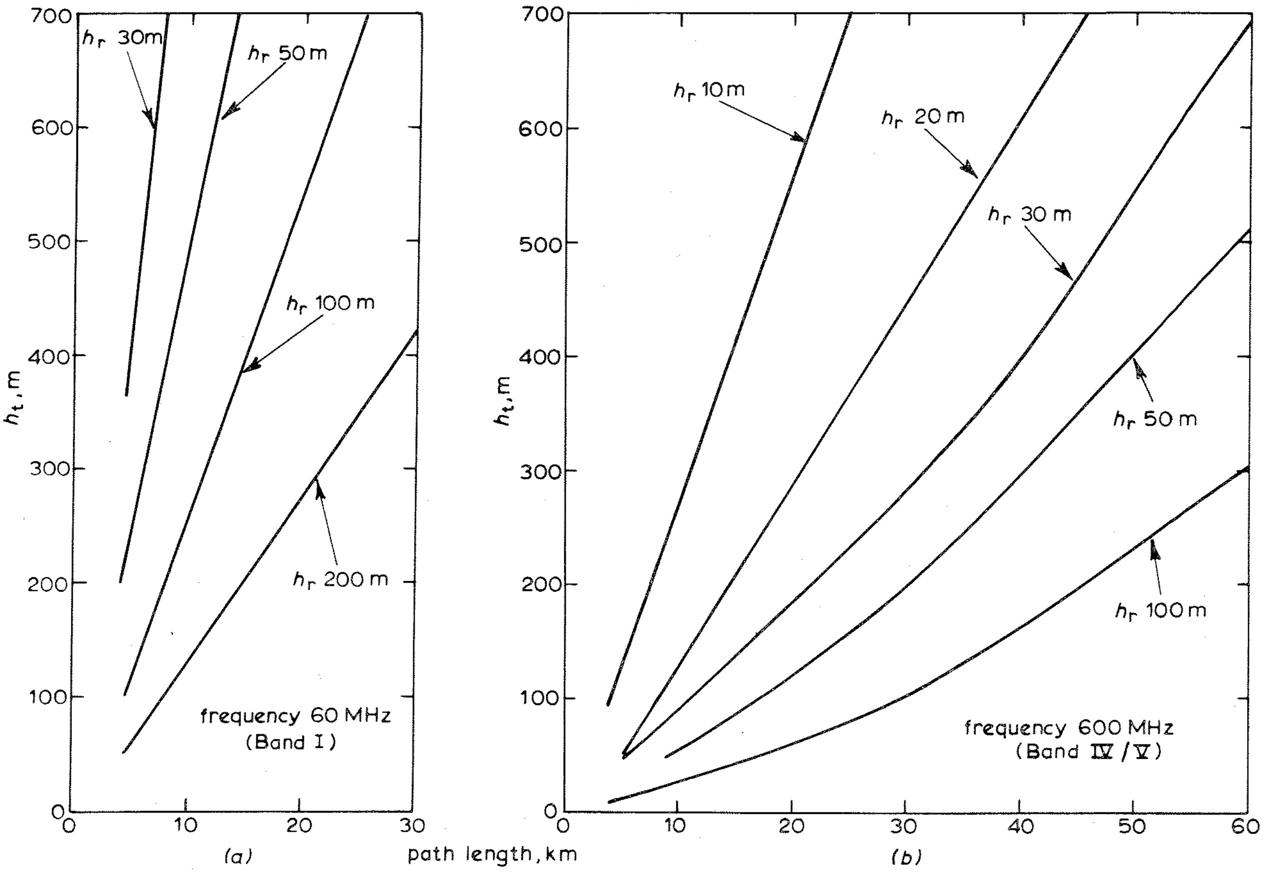

Fig. 2 - Maximum path lengths for two-ray cancellation

h_t and h_r being as in Fig. 1 Earth curvature factor = 4/3

ϕ is the phase delay on reflection also in wavelengths; it is approximately equal to ½ for horizontally-polarised signals and for vertically-polarised signals at small grazing angles.

In Fig. 2 are shown the ranges at which the most distant minimum* (n = 1) occurs for various combinations of effective terminal heights.

2.2. Reception at V.H.F. (Band I)

From Fig. 2(*a*) it may be seen that at frequencies in Band I, unless the terminals are at considerable heights, the maximum range at which nulls can occur is generally less than 10 to 15 km. Under these conditions of short range and high terminals the grazing angle at the reflection point will generally be at least 1°. For such angles the reflection coefficient for horizontal polarisation is nearly unity (for a smooth reflecting surface) but for a vertically-polarised transmission may be substantially less than unity. (Typical reflection coefficient curves for sea water at v.h.f. and u.h.f. are shown in Fig. 3.) Table 1 gives reflection coefficients for distances corresponding to the most distant minimum, i.e. to the smallest grazing angle. It will be observed that at the range of the most distant minimum, the lowest field-strength for vertical polarisation will be approximately 5 dB below free-space values for oversea paths, and 17·5 dB below free-space values for overland paths.

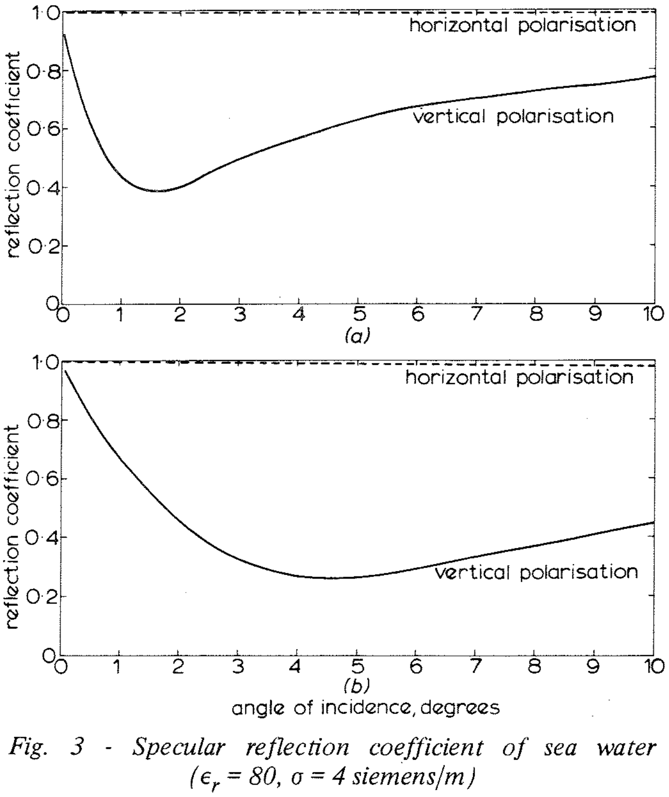

Fig. 3 - Specular reflection coefficient of sea water (ϵ_r = 80, σ = 4 siemens/m)

Abscissa corresponds to angle α in Fig. 1

(*a*) 60 MHz (*b*) 600 MHz

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* Plotted for horizontal polarisation and a sea reflection. The distances are virtually identical for other conditions at u.h.f. and are comparable for other conditions at v.h.f.

TABLE 1

Reflection Coefficient for Vertically-Polarised Transmission at 60 MHz at Distances Corresponding to the Furthest Field Minimum (n = 1)

	(a)	(b)	(c)	(d)
h_t	500m	500m	200m	500m
h_r	50m	100m	200m	200m
Distance	10km	17·5km	15km	35km
Grazing angle	3·2°	2·0°	1·5°	1·1°
Reflection coefficient (sea) $\epsilon_r = 8$				
$\sigma = 4$ siemens/m	0·5	0·4	0·38	0·42
Reflection coefficient (land) $\epsilon_r = 10$				
$\sigma = 2 \times 10^{-3}$ siemens/m	0·67	0·78	0·83	0·87
Resultant of direct and reflected components at minimum relative to direct component alone (dB) (a) sea	−6	−4·5	−4	−5
(b) land	−9·5	−13	−15·5	−17·5

The great majority of Band I and Band III transmitters involving sea reflections within the service area are vertically polarised. Table 2 summarises the horizontally-polarised stations serving areas over sea paths, but it should be noted that (particularly for the Band I stations) the terminal heights are generally insufficient to provide nulls within the areas mentioned.

TABLE 2

Horizontally-Polarised V.H.F. Television Transmitters Serving Areas Involving Sea Reflections

Transmitter		Tx. Ae. height m a.o.d.	Oversea Area Served	Distance from Tx (km)
Band I	Band III			
Blaen Plwyf		300	Lleyn Peninsula and Cardigan Bay coast	15 – 65
	Arfon	585	S.W. Anglesey and Cardigan Bay coast	16 – 100
Divis		510	Isle of Man and S,W. Scotland	65 – 95
Les Platons		185	Guernsey and Sark	20 – 40
	Fremont Point	280	Guernsey and Sark	20 – 40
Morecambe Bay		320	S. Cumberland and North Lancs	6 – 30
Redruth		380	Coastal areas of Cornwall	15 – 25
Rosemarkie		315	Easter Ross, Nairn and Moray	6 – 60
	Mounteagle	450	Easter Ross, Nairn and Moray	6 – 60
	Sandale	510	S.W. Scotland	25 – 85
	Caldbeck	580	S.W. Scotland	25 – 85
Skriaig		450	Scottish Mainland and Outer Hebrides	25 – 70
	Durris	610	Fife and East Lothian	70 – 120

Whilst nulls can occur with horizontally-polarised transmissions over paths involving land reflections, these will occur only when the reflecting area is sufficiently smooth to provide specular reflection. The usual criterion is that the reflecting surface can be considered as 'rough' if the magnitude of the surface irregularities exceeds $\lambda/8 \sin\alpha$ where α is the grazing angle; this is known as the 'Rayleigh roughness criterion'. With large terminal heights the grazing angles at the earth's surface are generally large, and thus the ground is often too rough to support specular reflection. Thus at v.h.f., particularly in Band I, signal nulls due to the cancellation of direct and reflected components are unlikely to be an important factor except for rare instances involving horizontally-polarised signals received over sea paths.

2.3. Reception at U.H.F.

It may be seen from Fig. 2(*b*) that in Bands IV and V the nulls due to cancellation of the two components of the received signal can occur up to considerable distances even for relatively low terminal heights. Fortunately terrain roughness is such that the effect of reflections over land paths can generally be neglected. However, the surface of the sea is usually sufficiently smooth to support specular reflection. At 600 MHz for a grazing angle of 1°, the Rayleigh criterion indicates that if surface irregularities are less than 3·7 m specular reflection will occur. The reduction in reflection coefficient for vertical polarisation is less at u.h.f. than at v.h.f. for normally occurring grazing angles (see Fig. 3); moreover since all u.h.f. main stations radiate horizontally-polarised transmissions this polarisation advantage is available only in relay station service areas.

In situations for which the path geometry remains constant it may be practicable to move a receiving aerial from a field-strength minimum by vertical displacement, a relative phase shift of $\lambda/12$ being sufficient to increase the resultant field from the minimum to a value of half the direct component. If, however, the reflection occurs at the surface of the sea the path geometry will vary according to the state of the tide.

Over short paths the vertical separation between field-strength minima will be small. If the tidal movement is greater than the vertical separation between minima, it will be impossible to position a receiving aerial so that minima will not occur. As the path length is increased the vertical separation between minima increases, and it may then become possible to position an aerial so as to avoid minima.

As the heights of the minima are dependent on frequency it will be seen that when transmission on four u.h.f. channels is to be considered it becomes even more difficult to avoid minima on all four programmes. At many locations two or three frequencies of a standard channel group may be affected by periods of greatly reduced field strength.

2.4. Direct and Reflected Rays

The two-ray theory is useful for calculations but neglects the presence of other components which have a marked effect on propagation on oversea paths. Components can be classified by their routes between transmitting and receiving aerials:

(i) Direct

On transmission paths within the horizon the amplitude of the direct component is the free-space field strength.

(ii) Specular Reflection from the Sea*

On oversea paths there is a component which is specularly reflected from the surface of the sea. At 500 MHz and a grazing angle of 1°, this component will be less than 0·1 dB below free-space for horizontal polarisation and less than 3·5 dB below free-space for vertical polarisation.

Additional reduction of this component will occur because of the divergence (caused by reflection from the convex surface of the earth). This loss will depend on the parameters of the transmission path but is generally in the range 0·05 dB to 0·5 dB.

The phase of the specular component is independent of the irregularities of the sea surface, and it corresponds to the average level of the sea within the first Fresnel ellipse. As the level of the sea varies, the phase alters relative to the direct component.

(iii) Diffuse Reflection from the Sea*

This component is caused by scattering from many small irregularities on the surface of the sea. As the irregularities move the resultant signal varies in amplitude and phase. The amplitude of this component is between 20 dB and 40 dB below free-space.

(iv) Land Reflections

These components result from reflections from land surfaces along the transmission path. Their amplitudes can approach free-space but at u.h.f. are generally lower, due to terrain roughness.

(v) Successive Land and Sea Reflections

It is possible for a component to undergo two successive reflections; one on land and the other on sea. The amplitude is generally similar to that of land reflections, but the relative phase varies with the tide.

A particularly interesting path which can occur at low tide is one involving successive reflections from the sea and a sloping beach. In this case the grazing angles at the reflection points can be very small and the amplitude of this component can be close to free-space values for both horizontal and vertical polarisations.

(vi) Multipath Propagation

Objects off the line of the transmission path generate reflected signals which have appreciable delay times relative to the primary components.

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* Estimates of the resultant field strength obtained by superimposing coherent (or specular) and incoherent (or diffuse) reflected components are discussed in Appendix I and elsewhere.[1]

On transmission paths where reflections occur from both land and sea, the fading range is generally less than on paths involving sea-reflection only. The principal minima may be displaced vertically due to the presence of these additional land reflected components, and also due to successive land and sea reflections, if these occur.

When the field strength is low, due to cancellation between the direct and specularly reflected components, multipath propagation will cause delayed images on the television pictures and distortion on the f.m. sound channel. Any diffusely-reflected component will cause a superimposed rapid variation.

Areas of the United Kingdom in which it is expected that the u.h.f. television service may be affected by tidal fading are detailed in Appendix II. Estimates of population affected are necessarily very approximate and in a number of instances alternative services are available.

2.5. Effects of Variations in Tropospheric Refraction

Variations of the vertical refractive index gradient of the atmosphere will cause changes in the effective earth's curvature,* and hence in the path difference between direct and reflected rays. This will result in a change of field strength at the receiving location.

In certain cases, the variation in path geometry due to tropospheric variations may be more important than changes due to tidal variations. For the Wenvoe to Lynton path (detailed in Appendix III), a change of effective earth's curvature factor* from 1·33 to 1·5 is equivalent to a change in path difference of 0·37λ, whereas a tidal range of ±3 m causes a change of only 0·25λ.

The refractive index variations cause vertical displacements of field strength minima, from those calculated for a standard atmosphere. On the path from Wenvoe to Lynton, this displacement will exceed 2 m for 33% of the time, and 11 m for 6% of the time. This vertical displacement of the minima is in addition to that occurring regularly due to tidal effects. The effect of tropospheric variations will be to cause day-to-day changes in the heights of the minima and thus alter the locations where tidal fading will occur. This obviously makes precise calculation of the vertical position of field strength minima very difficult.

Calculations have been made for certain other oversea paths, and the results of these are also shown in Appendix III.

3. MEASUREMENTS AT GREAT ORMES HEAD

In order to assess the severity of tidal fading under conditions with easily calculable path geometry prolonged recordings of a u.h.f. transmission were made over a path subject to this form of fading and involving a high receiving terminal.

The transmission path selected was that between the Llanddona (Anglesey) u.h.f. station and the BBC link site at the Great Ormes Head. This path is of particular significance in view of the possible requirement to receive the Llanddona programme at this site for onward transmission at s.h.f. to Moel-y-Parc.

3.1. Path Geometry

Path details are as tabulated:

(i) Transmitter: Llanddona Channel 63
Vision frequency 807·25 MHz
Sound frequency 813·25 MHz
Transmitting aerial height (h_t) 252 m a.m.s.l.

(ii) Receiving site: Great Ormes Head Site height = 200 m a.m.s.l.
Receiving aerial at 12 m a.g.l. (h_r) = 212 m a.m.s.l.

(iii) Path length (d) = 18·5 km.

(iv) Elevation of transmitting aerial from receiving location 0·2°
Elevation of transmitting aerial from sea reflection point = 1·2°
Transmitting aerial beam tilt 0·6°

(v) Tide heights, Conway Bay (a) Springs ±3·4 m
(b) Neaps ±1·8 m

(vi) Path difference at mean tide between direct and reflected signals

$$\frac{2h_t h_r}{\lambda d} \times \eta \text{ wavelengths} = 15{\cdot}22\lambda \text{ at vision carrier frequency}$$

$$= 15{\cdot}33\lambda \text{ at sound carrier frequency}$$

(vii) Path differences at spring tides:

	Vision frequency	Sound frequency
Low tide	15·68λ	15·79λ
High tide	14·75λ	14·85λ

(viii) Path differences at neap tides:

	Vision frequency	Sound frequency
Low tide	15·46λ	15·56λ
High tide	14·98λ	15·08λ

(ix) Path difference variation over tide range

(a)	Springs	0·95λ
(b)	Neap	0·48λ

From the tabulated path difference variation (item ix) it may be seen that at spring tides the range is almost a full wavelength, thus rendering impracticable any attempt to position a receiving aerial to avoid the null, even if only a single transmission were to be received. Since the angles of depression towards the receiving site and towards the reflection point are almost equally disposed on upper and lower skirts of the main beam (item iv), and since the sea reflection coefficient is virtually unity, the theoretical ratio of direct to reflected components will be determined primarily by the divergence factor. This factor is approximately 0·98 implying an expected maximum to minimum field strength ratio of 40 dB.

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* The negative vertical refractive index gradient results in a bending of radio waves towards the earth. This is equivalent to the assumption of a straight radio ray path over an earth of radius increased by a curvature factor dependent upon the refractive index gradient, being ≈ 4/3 for normal tropospheric conditions.

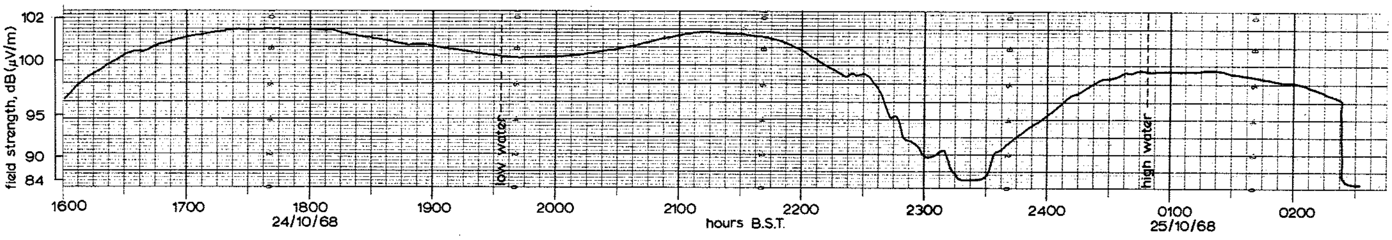

Fig. 4 - Record showing maximum vision signal (Channel 63) received at Great Ormes Head from Llanddona

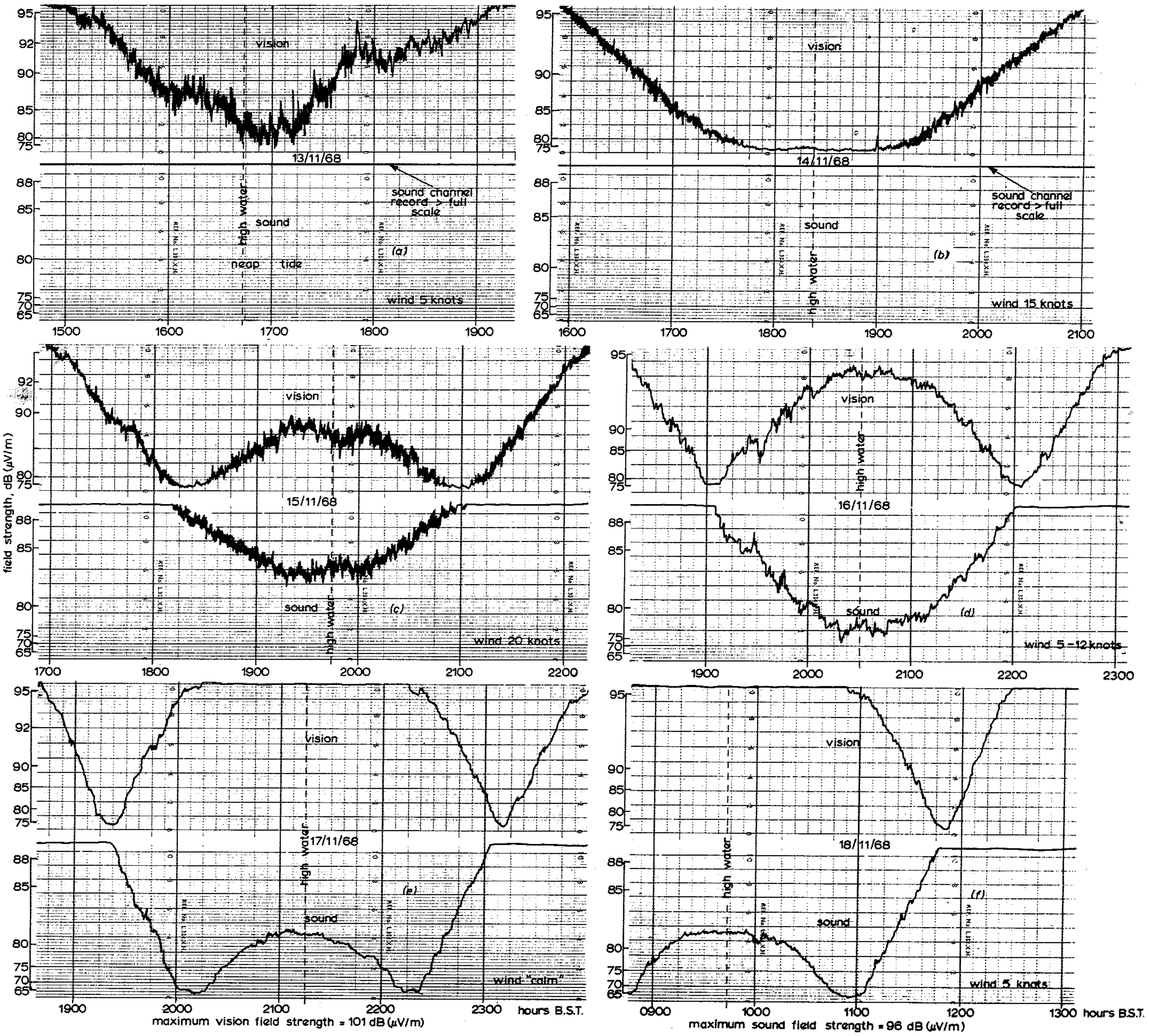

Fig. 5 - Llanddona u.h.f. service (Channel 63) received at Great Ormes Head Receiving aerial 12 m above ground level

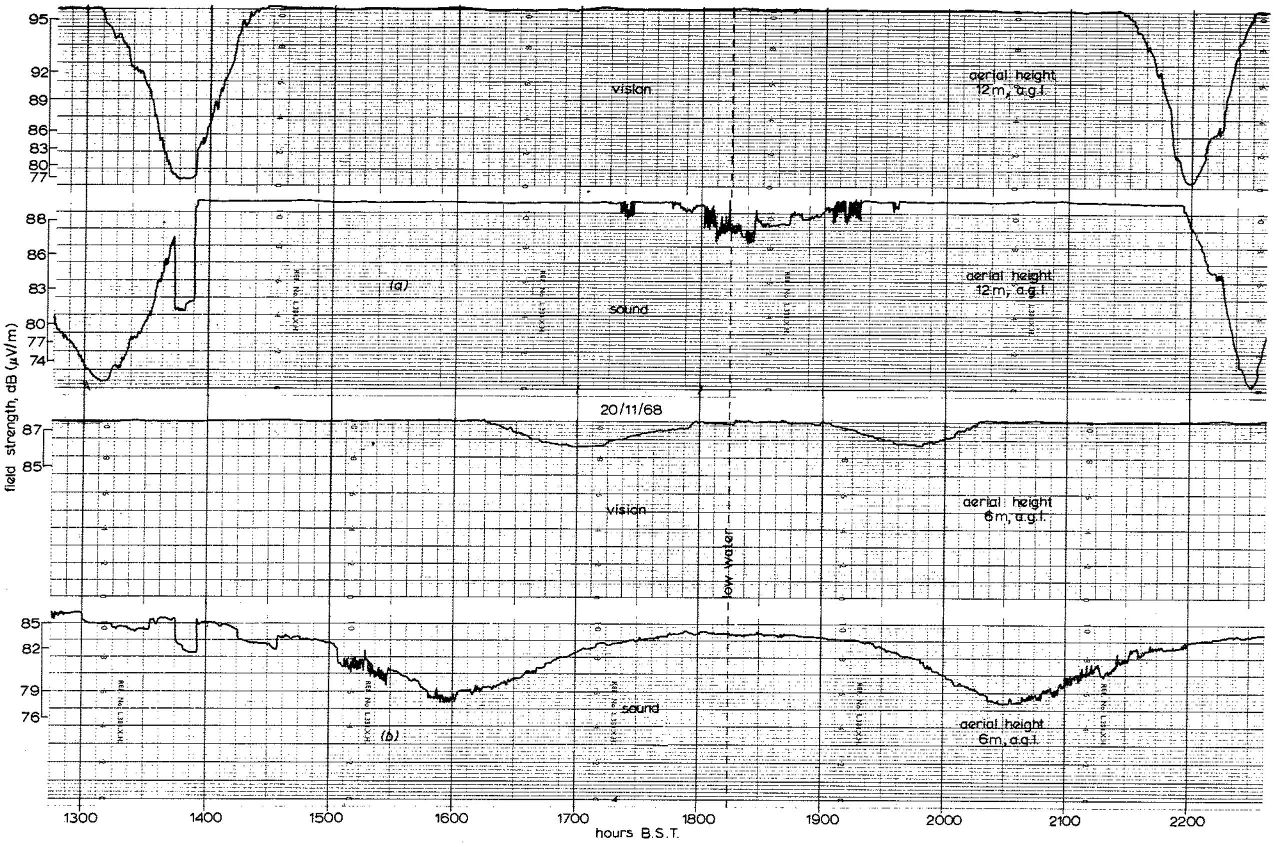

Fig. 6 - Comparative records at receiving aerial heights of 12 m and 6 m above ground level
Llanddona transmission received at Great Ormes Head

From items (vii) and (viii) it can be seen that the frequency difference between sound and vision carriers corresponds to a change in path length difference of 0·1λ. This implies that when one carrier has direct and reflected components in antiphase the resultant field at the other frequency is only 4·5 dB below the free-space value.

3.2. Results and Discussion of Results

3.2.1. Results with Receiving Aerial at 12 m a.g.l.

Typical sections of record obtained are reproduced in Figs. 4, 5 and 6(*a*). Since the receiver output law was linear the overall range was only 20 dB and consequently it was not possible to record the full range of signal variation. Fig. 4 shows signal maxima and Figs. 5 and 6(*a*) the minima, albeit limited by receiver sensitivity. From Fig. 4, which shows 10½ consecutive hours of vision signal record obtained two days after a spring tide, two features may be noted:

(1) The minimum field occurs at approximately 1/3 of the tide cycle from the high tide. This is as expected from item (vii) of the previous section which showed the vision frequency path difference at spring high tide to be 14·75λ and at low tide to be 15·68λ (cancellation occurring at 15λ).

(2) Since the maximum signal does not occur at either extremity of the tidal cycle the 'in-phase' condition must be attained at some part of the cycle, again as predicted in (vii). This maximum measured field was 101·5 dB (μV/m). The measured maximum sound carrier field strength was 5·5 dB below the maximum vision carrier value.

Fig. 5 represents a series of records of both sound and vision signals obtained on consecutive days commencing on a day of tidal neaps. This sequence is continued in Fig. 6(*a*) which corresponds to the following spring tides. In each record only the portions showing minima are reproduced. The following features may be deduced:

(i) The duration and form of the fading varies significantly from day to day according to the height of tidal maximum. On the second day, (Fig. 5(*b*)) the high tide level corresponds almost exactly to the condition for cancellation at the vision frequency, the minimum therefore extending over the period of slack water.

(ii) Consequent to the differential path difference of 0·1λ between sound and vision frequencies the times of occurrence of minima are substantially different, and thus there are prolonged periods when vision/

sound and chrominance/luminance ratios are severely altered.

(iii) The effect of sea roughness is demonstrated in Figs. 5(*a*) to 5(*d*) which may be compared to the relatively calm days represented in Figs. 5(*e*) and 5(*f*).

(iv) Although the receiver sensitivity at the time of the records in Figs. 5 and 6(*a*) is greater than for Fig. 4 the minimum field strength is still less than could be measured, i.e. less than approximately 75 dB (μV/m) at vision frequency and 68 dB (μV/m) at sound frequency. Thus the total excursion of signal level substantially exceeds 26 dB, corresponding to an effective reflection coefficient exceeding 0·9.

3.2.2. Results with Receiving Aerial at 6 m a.g.l.

The positioning of the link tower at the Great Ormes Head is such that there is a flat-roofed single-storey building in close proximity to the tower on the bearing towards Llanddona. It is therefore possible, by mounting the aerial just above the level of this roof (approximately 6 m a.g.l.), to ensure that the line-of-sight path to the transmitting aerial is maintained, whilst the path from the sea reflection is obstructed.

In Fig. 6 are shown simultaneous recordings of signal received at the original 12 m a.g.l. aerial and at the shielded aerial at 6 m a.g.l. Whereas, as previously discussed, deep minima occur at the upper aerial the minimum fields recorded at the lower aerial are 86 dB (μV/m) and 77·5 dB (μV/m) for vision and sound carrier respectively. Corresponding field maxima on this lower aerial are 95 dB (μV/m) and 88 dB (μV/m), thus indicating an overall fading range of 9 dB as compared to the value in excess of 26 dB at the upper aerial.

A fading range of 9 dB corresponds to a reflection coefficient of approximately 0·5 and to a direct signal component at vision frequency of 92 dB (μV/m). Thus the proximity of the shielding building has reduced the direct component of field relative to that at the upper aerial by 3·5 dB, but has reduced the reflected component by 9·5 dB.

The range of fading could also have been reduced by use of a suitable phased array of two vertically-spaced aerials. To produce the same degree of reduction (to an overall range of 9 dB from maximum to minimum) for a differential angle of arrival of 1·4° between direct and reflected components would require a vertical separation of 5 m. Complete cancellation of the sea-reflected signal would require a spacing of 7·5 m assuming the array to be phased to have its maximum corresponding to the angle of arrival of the direct component. Whilst theoretically it is possible to discriminate effectively against the unwanted sea reflected component at the expense of a reduced maximum field strength with a smaller vertical spacing between aerials, attainment of optimum phasing would present severe practical difficulties (bearing in mind that phasing tests could usefully be carried out only at the critical period of the tide cycle).

Alternatively, the fading may be minimised by employing diversity reception with vertically-spaced aerials. Although suitable for use at u.h.f. relay stations, the expense of such a system would be prohibitive for domestic purposes; a simpler manual system of aerial switching could be adopted by viewers in areas where no alternative service is available.

It should be noted that standard domestic receiving aerials are not capable of discriminating between the direct and sea-reflected components because at most locations the angular separation between the two components is less than 2°.

TABLE 3

Field Strength Variations at Unobstructed Locations

Location	1	1	2	3
Aerial height (a.g.l. – m)	10	2·8	10	3
Site height (a.m.s.l. – m)	30	30	31	44
Distance from transmitter, km	17	17	17	17·1
Tide range (m)	4·8	4·8	4·9	4·9
Number of minimum (n in Equation 1)	4	3	*	4
Maximum field (dB rel. free-space)	+6·5	+6·0	+7·0	+1·5
Minimum field (dB rel. free-space)	–14·5	–16·5	–2·5*	–20
Theoretical minimum (dB rel. free-space) (Two-ray approximation)	–39	–41	*	–39
Measured range of field strength, dB	21	22·5	9·5*	21·5

* Minimum field at low tide: condition of complete cancellation not attained

4. MEASUREMENTS IN ST. IVES

4.1. General

During the West Cornwall u.h.f. site test, variations of field strength with the tide were observed in St. Ives. Measurements of a horizontally-polarized 666 MHz transmission from Redruth were made at various locations in and around St. Ives, at receiving aerial heights of 2·8 m and 10 m above ground level (a.g.l.).

The tidal range at St. Ives varies from 1·8 m at neap tides to 5 m at spring tides. This corresponds to a path difference variation at 30 m above mean sea level (a.m.s.l.) of approximately 0·1λ to 0·25λ.

4.2. Results and Discussion of Results

4.2.1. Variations of Field Strength at Unobstructed Locations

The results of four continuous recordings made at three unobstructed locations in St. Ives are summarized in Table 3.

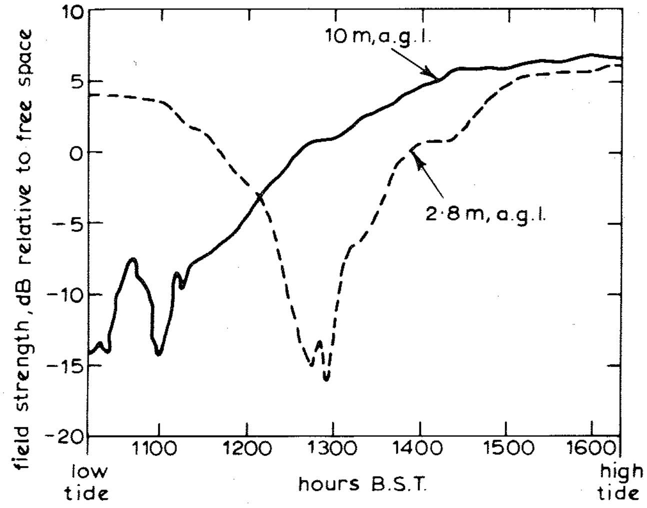

Fig. 7 - Variation of field strength over a half tide cycle at St. Ives (Location 1)

Simultaneous recordings at two receiving aerial heights

The two recordings at location 1 were made over the same period; the results are shown in Fig. 7. The field strength at 10 m a.g.l. appears to have been a minimum at low tide and had increased to slightly more than 6 dB above free-space by high tide, while the field strength at 2·8 m a.g.l. was a minimum near mean tide. It will be noted that the variations at 10 m a.g.l. will be considerably reduced at neap tides (when a minimum of 1 dB to 2 dB below free-space would be expected). The large differences between measured and theoretical minima are considered to be due to the presence of additional components.

Receiving aerial height gain observations show that some additional reflected signals of relatively high amplitude are present; some examples of these observations are shown in Fig. 8. At receiving aerial heights above 5 m the curves show ripples every 1 m to 1·2 m, and these are probably caused by a component reflected from an area near the shore on the transmission path. At low aerial heights the deviations from the 'two-ray' calculated field indicate further components of amplitude 0·5 to 1·0 times the free-space value. Components of this magnitude must be arriving in the main beam of the receiving aerial and hence would probably not have a significant delay relative to the primary signal. Components giving rise to delayed image interference would not be detected unless their path length changed appreciably over the range of aerial heights.

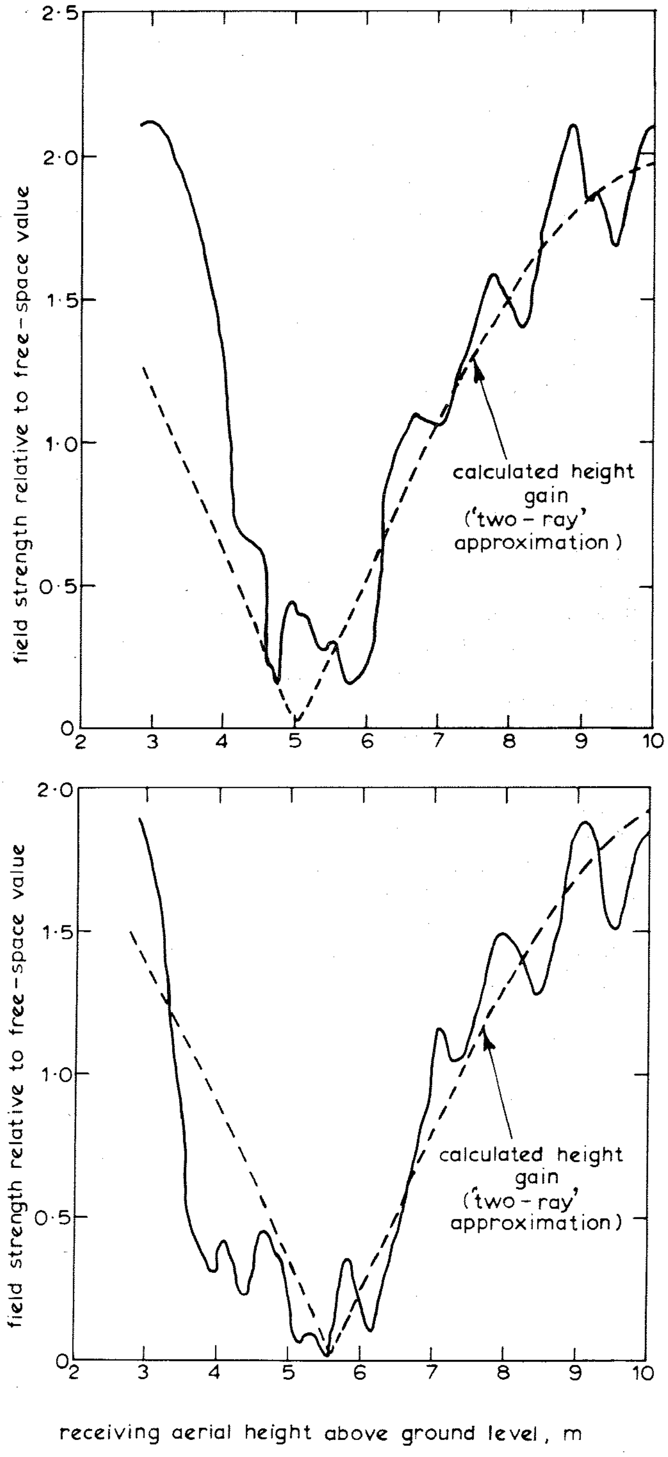

Fig. 8 - Examples of receiving aerial height gains

Measured at two receiving locations in St. Ives

The results given above have all been derived from observations made in a small area of St. Ives, but measurements made over half-tide cycle (6¼ hours) at a location to the east of Mousehole showed similar interference patterns due to additional rays. Continuous recording at 10 m and 2·8 m were supplemented by receiving aerial height gain measurements taken at hourly intervals. These height gain curves, shown in Fig. 9, illustrate changes in field strength with receiving aerial height; the range of field strength at 10 m was 12 dB, whilst ranges of up to 24 dB occurred between 6·2 m and 7 m with a peak range of 26 dB at 8·1 m. In some of the deeper minima where the fields were of the order of –22 dB rel. to free space, rapid fluctuations of field strength of the order of ±5 dB were observed.

4.2.2. Variations of Field Strength in Built-up Areas

The results of continuous recordings made behind obstacles are of limited value since in nearly all cases either a maximum or a minimum field occurred at one extreme of the tide, or when the recording had to be discontinued. However the results give an indication of the order of the ranges in field strength occurring in different areas in St. Ives. The results are listed in Table 4 in terms of approximate path attenuation of the direct ray and are grouped according to the nature of the diffraction.

The presence of additional rays was indicated by ripples on the recordings, particularly in the deeper minima, which had the effect of increasing the minimum field strength. Table 4 shows that field-strength variations were small at locations behind more than one diffracting edge.

5. MEASUREMENTS IN SOMERSET AND DEVON

5.1. General

Although the measurements in St. Ives indicated that severe fading could occur due to tidal changes, the use of a c.w. transmission provided no information about the subjective effects of this type of fading on television signals. To obtain additional information, measurements were made on u.h.f. transmissions (Channel 51) from the BBC station at Wenvoe (near Cardiff). The paths investigated, all of which crossed the Bristol Channel, varied in length from 26 to 46 km. Tidal ranges depended on the position of the reflection point in the Bristol Channel, and were approximately 9·5 m to 12 m at spring tides and 4·5 m to 6 m at neap tides.

Continuous recordings of field strength were made over half-tide cycles (6¼ hours) in and around the major population centres. At each location separate chart recordings were made on three frequencies: 711·25 MHz vision, 717·25 MHz sound, and a 756 MHz c.w. site test transmission. The television transmissions were horizontally polarised, the transmitting aerial height being 343·3 m a.o.d. The 756 MHz transmission, which was radiated from a low-power transmitter using vertical polarisation at an aerial height of 312·5 m a.o.d., allowed comparisons to be made between vertical and horizontal polarisation.

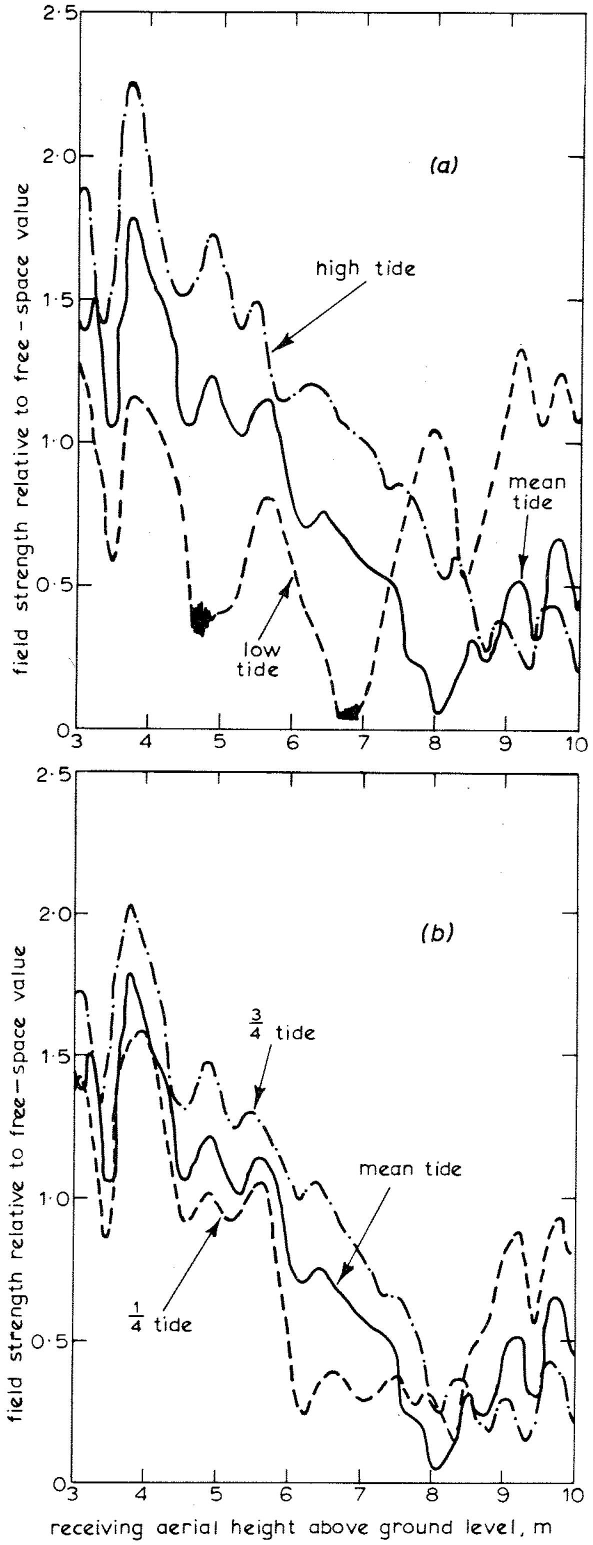

Fig. 9 - receiving aerial height gains at various states of the tide

Measured at a receiving location near Mousehole (Cornwall)

Recordings of field strength were made as the receiving aerial was raised from 2·8 m to 10 m above ground level, at a number of points in Minehead, Lynton and Weston-super-mare. These 'height-gain' recordings were repeated

TABLE 4

Field Strength Variations in Built-up Areas

	Tide range m	Aerial height a.g.l. (m)	Path attenuation due to diffraction (dB)	Measured field strength range (dB)
(A) Single obstacle	3·1*	2·8	30	10*
	5·4	2·8	23	17
	3·0	10	21	10*
	4·8	2·8	16	9
	4·9	2·8	15	9
	4·8	10	3	14
(B) More than one diffracting edge	4·7	2·8	38	5
	4·8	2·8	19	2
	4·7	10	16	4
(C) More than one diffracting edge, sea-reflected ray attenuated on the far side of the bay	5·1	2·8	34	3
	5·1	10	22	2

* Recording over 3 hours

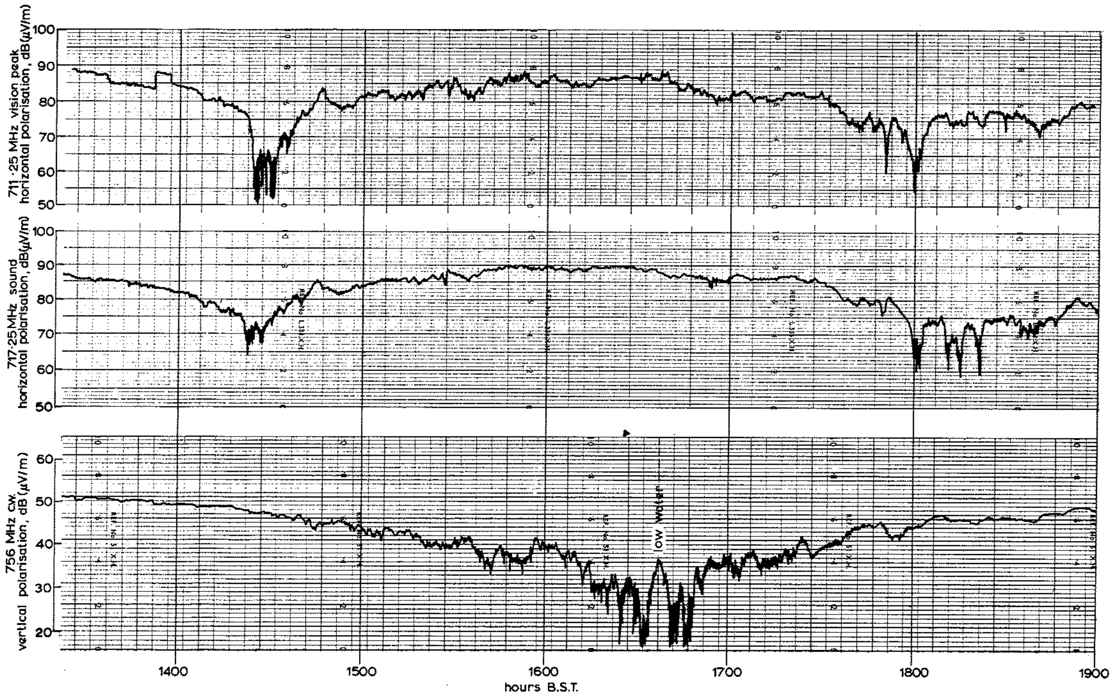

Fig. 10 - Example of simultaneous recordings at three frequencies

at a different time in the tide cycle and the two sets of charts were then compared for evidence of variations attributable to tidal fading.

Throughout these tests the Wenvoe Channel 51 BBC-2 transmission was monitored on a Bush CTV 174D 500 mm colour receiver, and subjective assessments of picture impairment were made.

5.2. Results and Discussion of Results

5.2.1. Continuous Recordings of Field Strength Over Half-Tide Cycles

Some examples of these recordings are shown in Fig. 10. The results are summarised in Table 5. At some locations no definite field strength minimum was recorded, and as it is possible that results obtained from such recordings are not typical of the maximum fading range in the local area, these recordings are marked with an asterisk.

Most of the recordings showed noticeable differences between times when the vision and sound carriers faded. As discussed in a previous section this variation of time of occurrence of fading with frequency is significant in that the fading on all of the four u.h.f. channels assigned to a station will occur at different times and the minima will be so widely separated vertically that it may not be practical to select a receiving aerial height to avoid fading on all four channels.

TABLE 5

Location	Frequency MHz	Polari-sation	Measured field strength Maximum dB(μV/m)	Minimum dB(μV/m)	Fading Range dB
Clevedon 1	711	H	107	82	25
	717	H	99	73	26
	756	V	54	40	14
Clevedon 2	711	H	90	80	10*
	717	H	82	79	3*
	756	V	38	19	19
Clevedon 3	711	H	89	73	16*
	717	H	81	69	12*
	756	V	40	20	20
Minehead 1	711	H	102	81	21*
	717	H	96	82	14*
	756	V	52	21	31
Minehead 3	711	H	102	55	47
	717	H	95	52	43
	756	V	48	29	19
Minehead 4	711	H	74	62	12*
	717	H	72	58	14*
	756	V	45	39	6*
Minehead 9	711	H	98	55	43
	717	H	95	60	35
	756	V	53	17	36
Lynton 1	711	H	99	55	44
	717	H	93	76	27*
	756	V		No Recording	
Lynton 10	711	H	67	40	27
	717	H	60	34	26
	756	V	11	N.L.	–
Lynton 14	711	H	82	76	6
	717	H	72	70	2
	756	V	35	30	5
Watchet 1	711	H	104	88	16
	717	H	100	84	16
	756	V	55	42	13
Weston-super-mare 1	711	H	99	82	17
	717	H	97	81	16
	756	V	52	40	12

* No definite field-strength minimum
N.L. Below receiver noise level

It was apparent from the recordings that as the field strength decreased rapid variations of field strength due to the diffuse sea-reflected component became noticeable. These fluctuations of field strength were occasionally large in amplitude; in one case (Minehead 3) the field strengths were varying between 50 dB (µV/m) and 75 dB (µV/m) over a period of 2 to 5 seconds. An examination of these rapid variations of field strength will be found in Appendix I.

5.2.2. Recording of Height Gain Variations with Tide

For each frequency two sets of 'height-gain' recordings, made at different states of the tide, were compared. Large differences between the two recordings were assumed to indicate that tidal fading had occurred. The change in field strengths between recordings gives some indication of the amplitude of fading likely to occur at the various locations. Examples of height-gain recordings are shown in Fig. 11.

At unobstructed locations the minima were often 25 to 35 dB below the field strengths observed at a different state of the tide. In built-up areas the corresponding reductions were usually 10 to 30 dB.

5.2.3. Differences Between Horizontal and Vertical Polarisation

At most locations the fading range for vertical polarisation was less than 20 dB, compared with up to 40 dB on horizontal polarisation, but it is difficult to compare them at any given location because the presence of ground reflections can increase the fading range on some frequencies whilst decreasing it on others.

For comparison of horizontal and vertical polarisations, the results of the recordings were analysed to produce average fading ranges for each polarisation. From these figures, the effective amplitudes of the specularly reflected components relative to the direct components were calculated. It is assumed that diffraction losses are equal for both polarisations; thus any differences in the relative amplitudes of the reflected components are caused by differences in reflection coefficient of the sea for each polarisation. If the reflection coefficient is taken to be unity for horizontal polarisation, the reflection coefficient for vertical polarisation can be derived from the measurements. The results are compared with the theoretical values in Table 6(*a*) and 6(*b*), derived respectively from averaged height-gain results in urban areas, and from continuous recordings at fixed locations.

TABLE 6(a)

Reflection Coefficients for Vertical Polarisation Averaged Results from Height-Gain Recordings in Urban Areas

Location	Measured Reflection Coefficient	Theoretical Reflection Coefficient
Lynton	0·78	0·84
Minehead	0·81	0·81

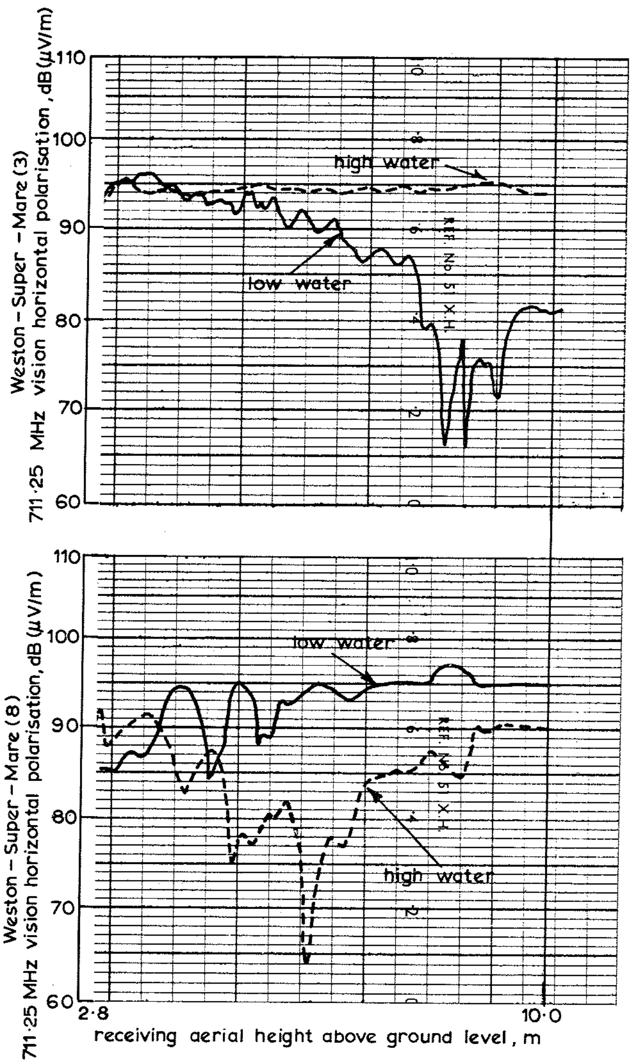

Fig. 11 - Variations of receiving aerial height gain between high and low tides
(height scale not linear)

TABLE 6(b)

Reflection Coefficients for Vertical Polarisation Results from Continuous Recordings at Fixed Locations

Location	Measured Reflection Coefficient	Theoretical Reflection Coefficient
Clevedon 1	0·72	0·78
Minehead 3	0·75	0·69
Weston-Super-Mare 1	0·82	0·78
Watchet 1	0·77	0·81

At most locations, the fading range on vertical polarisation was less than 20 dB. Theoretical reflection coefficients suggested that the maximum fading range across the Bristol Channel would be about 19 dB.

TABLE 7

Theoretical Fading Ranges for Vertical Polarisation Over Sea Paths

Distance Between Transmitter and Receiver (km)	Grazing Angle at the Sea	Calculated Fading Range (Maximum/Minimum) dB
5	3·9°	4·8
10	1·9°	8·8
20	0·9°	14·6
40	0·4°	20·5

Frequency: 500 MHz Polarisation: Vertical
Transmitting aerial height: 300 m a.s.l.
Receiving aerial height: 30 m a.s.l.
Earth's curvature factor: 1·33

For horizontal polarisation, fading ranges of more than 40 dB were recorded. It is thus obvious that the fading range is significantly less for vertical polarisation at the distances involved in these tests. At locations nearer to the transmitting site the advantage of vertical polarisation would be even more marked; Table 7 gives some examples of the expected fading ranges for various path lengths using vertical polarisation.

5.2.4. Subjective Assessments

Three distinct and separate forms of picture degradation were noted during tidal fading:

(a) Delayed image interference

(b) Frequency selective fading

(c) Receiver noise

(a) The delayed image interference was due to reflections from obstacles in high ambient fields at times when the direct signal at the receiver was reduced by tidal fading. This interference varied from location to location, but typically for the transmitter power under consideration the vision signal was severely degraded when the signal had been reduced to a level of approximately 20 to 25 dB below free space. Comparable impairments were observed on monochrome and colour receivers. The sound signal, being more tolerant of this form of interference, was similarly degraded at about 30 dB below free space.

(b) Frequency-selective fading occurred at higher receiving locations, where there was a considerable path difference between direct and reflected components and there was a significant difference between the times when the vision and sound carriers faded. At some locations differences of up to 1½ hours were noted. Such frequency-selective fading caused large changes in chrominance-luminance and sound-vision ratios. Variations of sound-vision ratios between −24 dB and +20 dB were measured. (The nominal sound-vision ratio is −7 dB.) The effects of frequency-selective fading only became noticeable after the picture had already been severely degraded by delayed image interference; Table 8 summarises the subjective effects of such fading.

TABLE 8

Subjective Effects of Frequency-Selective Fading

Carrier with greatest attenuation	Effect
Sound	Reduction of sound level. Severe multipath distortion on sound. Slight reduction of colour saturation.
Colour subcarrier	Reduction of colour saturation*, with little or no change of colour hue. During the most severe fading the picture changed to monochrome
Vision	Oversaturation of colours, with periods of incorrect colour. Loss of line and field synchronisation. Delayed image interference.

* The colour receiver used for these tests employed chrominance a.g.c. It may be expected that the effect of frequency selective fading would be more pronounced on receivers without this facility.

Most domestic television receivers have common automatic gain control (a.g.c.) for sound and vision. The receiver a.g.c. is usually derived from the vision carrier, and thus if the vision field strength remains constant no compensation for changes in sound field strength will be made by the receiver. This was found to be particularly objectionable when the sound field strength was low, because rapid variations of field strength (up to 25 dB) occurred every 2 to 5 seconds, causing a corresponding change in sound output level.

(c) In areas of high ambient field strength, receiver noise was not a significant factor in picture degradation. In these areas degradation was primarily due to delayed image interference.

Areas of low ambient field strength, caused by screening from the transmitter, may be affected by receiver noise. In these areas the fading is normally reduced but the small reduction of field strength due to tidal fading may significantly reduce the signal-to-noise ratio.

6. CONCLUSIONS

As predicted from theoretical considerations, severe fading of u.h.f. transmissions due to reflections from the sea can occur on oversea paths. At unobstructed locations, changes in field strength of more than 40 dB have been observed. In urban areas, the fading range was generally between 10 dB and 30 dB. Use of vertical polarisation could reduce the fading range and it would be advantageous in some cases to employ vertical polarisation for transmissions likely to be affected by tidal fading.

Severe degradation of service quality occurs during the period of fading because of multipath propagation which causes delayed images on the picture and distortion of the sound. At certain locations, this degradation is accompanied by frequency-selective effects.

When four programmes are transmitted on u.h.f., the fading will occur at different times for each programme and at many locations it will be impossible to position the receiving aerial so that tidal fading is avoided on all four channels. Some improvement may be expected if the receiving aerial can be screened from the sea reflection.

Diversity reception using vertically-spaced aerials would minimise the effects of tidal fading, but the expense of such an installation may be too high for domestic purposes. Alternatively adequate reduction in fading range may be achieved by an array of two co-phased vertically-spaced aerials. Since, however, the required separation is likely to exceed 3 m this may present problems of aerial mounting and phasing.

On certain paths, variations in tropospheric refraction can change the times and locations at which tidal fading occurs.

Appendix II details the areas of the United Kingdom in which it is expected that the u.h.f. television service may be affected by tidal fading. With two exceptions the areas affected are served by horizontally-polarised main stations, but the possibility of service impairment due to this form of fading must also be considered in planning future u.h.f. relay stations in coastal areas.

7. REFERENCES

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2. Influence of the non-ionised atmosphere on wave propagation : some statistics of the variation with height of tropospheric radio refractive index in the United Kingdom. CCIR Study Group V, Document V/12-E.

3. HALL, M.P.M. *and* COMER, C.M. 1969. Statistics of tropospheric radio-refractive-index soundings taken over a 3-year period in the United Kingdom. *Proc. IEE,* **116**, 5, 1969, pp. 685 – 690.

APPENDIX I

Measured Amplitudes of the Sea-Reflected Components

As discussed in Section 2.4 the observed phenomena may be explained on the basis that there are two modes of reflection from the sea; specular reflection and diffuse reflection.

From some of the continuous recordings, the amplitudes of these two components have been derived. These are shown in Table 9.

It should be noted that some of these recordings were made in obstructed locations. Therefore, some variations in the amplitude of the sea-reflected components would be expected between locations.

At unobstructed locations, the amplitudes of the specularly-reflected components were approximately 0·5 dB below the direct component for horizontal polarisation, and 3 dB for vertical polarisation.

TABLE 9

Location	Frequency MHz	Maximum dB (μV/m)	Minimum dB (μV/m)	Fading range dB	Eo dB (μV/m)	Es dB rel. Eo	Ed dB rel. Eo
Clevedon 1	711	107	86	21	102	–1·5	–30
	717	99	78	21	94	–1·5	–29·5
	756	54	41	13	50	–4·0	–27
Clevedon 2	711						
	717						
	756	38	22	16	33	–2·8	–27
Clevedon 3	711	89	74	15	84·5	–3·2	–24·5
	717	80	70	10	76·5	–5·7	–24
	756	40	28	12	36	–4·5	–15
Minehead 1	711	102	82	20	97	–1·7	–23
	717	95	83	12			
	756	52	29	23*	47	–1·1	–27
Minehead 3	711	102	66	36	96	–0·3	–23
	717	95	63	32	87	–0·5	–23
	756	49	34	15	44·5	–3·2	–22·5
Minehead 9	711	98	61	37	92	–0·3	–33
	717	95	66	29	89	–0·6	–29
	756	53	19	34*	47	–0·4	–30
Lynton 1	711	100	62	38	94	–0·3	–35
	717						
	756						
Lynton 10	711	67	45	22	62	–1·3	–28
	717	59	37	22	54	–1·3	–26
	756						
Weston-Super-Mare 1	711	98	84	14	93·5	–3·6	–26·5
	717	97	82	15	92·5	–3·2	
	756	52	42	10	48·5	–5·7	–23·5

* Not valid due to successive sea and land reflections

Eo Amplitude of direct component
Ed Amplitude of diffusely-reflected component
Es Amplitude of specularly-reflected component

The amplitudes of the diffusely-reflected components were generally between 20 dB and 30 dB below the direct component. There was no significant difference between horizontal and vertical polarisations. It is possible that variations in the roughness of the sea may have caused changes in amplitude of this component, but not enough measurements were made to confirm this.

An example of a high-speed chart recording of field strength variations caused by the diffuse component is shown in Fig. 12.

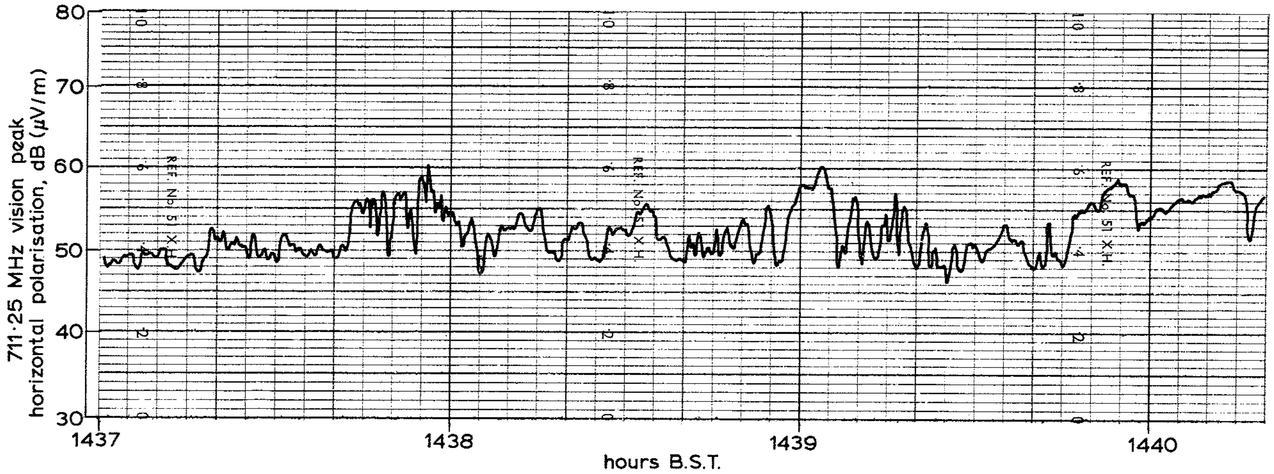

Fig. 12 - Example of high speed chart recording showing rapid variations of field strength

APPENDIX II

Calculations have been made to determine populated areas in which tidal fading is likely to occur at u.h.f. The results are tabulated below for each of the transmitter areas affected.

It should be noted that only parts of the towns and villages listed will experience tidal fading, and that some of these will have alternative services from other u.h.f. stations.

Where a relay station is using vertical polarisation, it is expected that the fading range will be reduced. Towns and villages in which the fading range is expected to be within acceptable limits are marked *.

Transmitter	Polarisation	Parts of Towns and Villages Affected	Approximate Population Affected
103·0 Winter Hill	Horizontal	Barrow-in-Furness	6,000
		Leece	200
106·0 Wenvoe	Horizontal	Clevedon†	2,500
		Lynton†	800
		Minehead†	2,500
		Portishead†	4,000
		Watchet†	2,000
		Weston-Super-Mare†	4,500
106·1 Kilvey Hill	Vertical	The Mumbles*	8,000
		Port Talbot*	500
113·0 Dover	Horizontal	Ramsgate	5,000
118·0 Llanddona	Horizontal	Deganwy	
		Dwygyfylchi	
		Llandudno	
		Llanfairfechan	2,900
		Penmaenmawr	3,500
122·0 Rosneath	Horizontal	Dunnoon	3,000
		Gourock	4,000
		Greenock	5,000
		Port Glasgow	15,000
122·1 Rothesay	Vertical	Largs	1,000
		Skelmorlie*	1,500
		Rothesay*	5,000
135·0 Blaen Plwyf	Horizontal	Aberayron	1,000
		Newquay	800
141·0 Redruth (West Cornwall)	Horizontal	Mousehole	500
		Newlyn	1,000
		Penzance	200
		St. Ives	2,000
147·0 Craigkelly	Horizontal	Edinburgh (Northern part)	45,000
		Cockenzie and Port Seton	3,100
		Gullane	6,300
		Lower Largo	3,500
		Prestonpans	17,200
		Tranent	2,600
		Wallyford	600
156·0 Rosemarkie	Horizontal	Nairn	500
158·0 North Kent	Horizontal	Southend	20,000

† An alternative service has been (or is to be) provided to these towns in order to satisfy national programme requirements.

APPENDIX III

Effects of Variations in Tropospheric Refraction

TABLE 10

Transmitting site	Receiving site	h_t a.m.s.l.	h_r a.m.s.l.	d km	Frequency MHz	Path difference		
						K = 1·33	K = 1·5	K = 2·0
Wenvoe	Weston-Super-Mare	353·5	19	25·7	711·25	1·11λ	1·13λ	1·15λ
	Lynton	353·5	128	46·7	711·25	3·44λ	3·56λ	3·81λ
Blaen Plwyf	Bwlch Mawr	326	268	74	519·25	2·12λ	2·38λ	2·74λ

h_t = transmitting aerial height (m)

h_r = receiving aerial height (m)

d = distance (km)

K = effective earth's curvature factor (K = 1·33 – standard atmosphere)

As mentioned in Section 2.5, variations in refractive index lapse rate can affect reception on oversea paths. To assess the effects of these variations calculations have been made for certain oversea paths, and some examples are given in Table 10.

Measurements of refractive index lapse rate made at Cardington (Beds)[2,3] indicate that a lapse rate in the first 150 m of height, corresponding to a curvature factor of 1·5, is exceeded for 33% of the time and to a factor of 2 for 6% of the time. Although no such measurements appear to be readily available for the lapse rate above the sea, experience indicates that these will generally be greater than over the land.

Any screening of the sea reflected component or any land reflections will reduce the severity of the fading. For example, tests on the Blaen Plwyf to Bwlch Mawr path have shown that tropospheric fading will not be as severe as suggested by these calculations.